FRICTION LOSSES IN

PIPE FITTINGS AND VALVES

A THESIS

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by

Eugene D. Ermenc

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PIPE FITTINGS AND VALVES

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To the memory of Dr. Harold A. Bunger, former head of the Chemical Engineering Department, I dedicate this work.

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INTRODUCTION

Literature Survey

In every pipe line system there is a loss in head due to the friction caused by the fluid flowing in the line. In addition to the loss in straight pipe, there is a considerable loss due to the fittings and valves in the installation, and many investigations have been made to determine these losses.

Work had been done as early as 1880 on flow in straight pipe but none on fittings and valves. Giesecke (1) was possibly the first to conduct a friction loss investigation on a fitting. The method of test consisted of allowing water to flow from one tank to another, with and without the given pipes and fittings in the connecting line. The fittings tested were elbows of one-half inch to three inches nominal pipe diameters.

D. E. Foster (2), using a modification of a formula

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(1) Giesecke, F.E., "Formulas Deduced for Friction Loss in Water Pipes and Fittings", Engineering News-Record, 79: 469: 1917.

(2) Foster, D.E., "Effect of Fittings on Flow of Fluids", Mechanical Engineering, 42: 616: 1920.

developed by Meier (3), calculated the losses for various type fittings and tabulated these losses for pipe sizes ranging from one-half inch to twelve inches in diameter. At the meeting in which Foster presented these values, Giesecke criticized the results, saying the values were inaccurate and based on false assumptions. It was brought out in the discussion that Meier's factor of resistance, "r", was not a constant for each type of fitting but varied with the diameter, and that Foster had assumed a constant value; therefore Foster's values could not be applied to every diameter. These values were subsequently corrected and can be found in handbooks (4) and textbooks (5). Later, experimental evidence was to show that some of his values were still incorrect.

Experimental work on flow through elbows was presented by Wilson, McAdams, and Seltzer (6) in connection with their work on the development of the friction loss chart

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(3) Meier, K., The Mechanics of Heating and Ventilating.

(4) Perry, J. H., Chemical Engineering Handbook, 1941. p. 825.

(5) Badger and McCabe, Elements of ChemicalEngineering, 1935, pp 34-43.

(6) Wilson, McAdams, and Seltzer, "The Flow of Fluids Through Commercial Pipe Lines", Journal of Industrial and Engineering Chemistry, 14: 105-19; 1922.

for straight pipe. Elbows of three sizes, one-inch, two inch, and four-inch, were tested. The one-inch elbows were separated by a spacer one foot, eight and three eighths inches in length, the two-inch elbows by a spacer one foot, one inch in length, and the four-inch elbows by a spacer one and one-quarter inches in length. The manometer connections were at least forty diameters above and below the elbows. The loss of one elbow was computed by subtracting the loss in the length of straight pipe from the total loss and dividing the remainder by two. Doubt was expressed as to the accuracy of the determination of loss in the four-inch elbows due to the short length of spacer. The same statement might also be made of the other elbow determinations.

Corp and Ruble (7) conducted an investigation of the friction losses in valves and pipes having diameters of one-half inch to twelve inches. They concluded that the loss in head due to valves and other fittings occurs in part within the valve or fitting and in part as an added loss in the pipe line downstream where normal flow has been disturbed. The measurement of loss of head where the downstream piezometer is attached too near the valve, according to the paper, will give a loss in excess of that actually produced. A recommen-

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(7) Corp and Ruble, "Experiments on Loss of Head in Valves and Pipes of $\frac{1}{2}$ in. to 12 in. Diameter", Mechanical Engineering, 45: 250-51: 1923

dation of from twenty to twenty-five pipe diameters beyond the valve was given as probably the best position for the downstream piezometer opening. The length of straight pipe which will produce the same loss of head varied from three-quarters of a foot to four feet for fully open gate valves, and from twenty to thirty-five feet for fully open globe valves.

A greater advance in this field was made by Perry (8) who tested new wrought iron fittings. Standard one-inch, one and one-half inch, two and one-half inch, and three-inch elbows were used. Discharge was measured by permitting water to flow into a calibrated tank and the velocity obtained by a simple calculation. An overflow was used to maintain a constant head, and the lost head was measured by making piezometer connections to differential gages. Care was taken to have the connections just flush with the inside of the pipe. Connections were made four to seven inches above and six to eight inches below the fitting. Piezometric connections to the one-inch pipe were made directly to a tee screwed to a nipple of proper length and in turn screwed into the fitting. Additional loss of head due to the extra tees was determined and proper allowances made.

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(8) Perry, L., "Tests of Loss of Head in Standard Elbows and Tees", Engineering News-Record, 92: 940: 1924.

It appears that the piezometric connections made by Perry were placed too close to the test fitting. The use of a tee as a piezometric connection for the one-inch pipe also brings up doubts as to the accuracy, since it appears that the tees, being so close to the fitting tested, would exert a disturbing influence on the flow through the fitting.

Corp and Hartwell (9) studied the losses in head for U, S, and twisted S pipe bends. This investigation disclosed that fifty per cent or more of the loss occasioned by an elbow occurs in the straight pipe below the fitting.

Additional work was done by Giesecke in cooperation with Reming and Knudson (10) on friction losses in elbows. The friction loss was measured with an air-water manometer which was connected by means of two piezometer rings, separated by ninety-one feet of pipe and thirteen standard 90° elbows. The loss due to the straight pipe was subtracted from the total loss and the remainder divided by thirteen to give the loss in one elbow. Similarly various types of elbows were tested. It was found that the friction loss in a three-inch long radius elbow was two-thirds the loss in a

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(9) Corp and Hartwell, "Experiments on Loss of Head in U, S, and Twisted S Bends", University of Wisconsin Engineering Experiment Station, Series Number 66.

(10) Giesecke, Reming, and Knudson, "Friction of Water in Elbows", Transactions of the American Society of Heating and Ventilating Engineers, 32: 303-14: 1926.

short radius elbow. It was also found that a 45° elbow caused about one-half the loss of a 90° short radius elbow.

Foster's table of friction losses of various type fittings and valves was being used extensively when the Crane Company (11) noticed that, in comparison with experimental data published, Foster's values were low. As a result they attempted to establish the correct data. The method of test consisted of placing a fitting in a water line and regulating the flow by a throttling valve situated at the end of the line. The pressure drop across the fitting was measured by a mercury manometer or by two sensitive low pressure gages, leads of which were situated at a distance of ten pipe diameters from each end of the fitting on test. It was concluded that globe valves offer a resistance to flow much greater than previously published values, and that screwed and flanged fittings offer equal resistances to flow. It is possible that the manometer connections were placed too close to the test fitting and gave incorrect results. The distance specified by Corp and Ruble (12) was twenty to twenty-five pipe diameters from the fitting for the downstream connection in order to obtain accurate values.

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(11) Crane Company, "Flow of Fluids in Pipes and Heat Transmission", Crane Company Publication, 1935, pp. 24-30.

(12) Corp and Ruble, loc. cit.

The values issued by the Crane Company have, however, superceded Foster's results as widely used values.

Bruins, Othmer, James, and Berman (13) conducted tests on one-half inch streamline fittings, correlating the results with the Reynolds number. The testing equipment consisted of ten lines, each line containing fittings of one type, so that nine different fittings were tested. One line contained straight pipe. Flow was varied and the pressure drops obtained. It was shown that the loss in streamline fittings was less than the pressure drop in iron pipe and fittings of the same actual internal diameter. It was also concluded that the pressure drop due to friction in the fittings is dependent upon the velocity of flow. From the illustrations in the paper, it is apparent that the manometer connections were placed too near the control valves to escape its disturbing influence; the results may thus be in error

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(13) Bruins, Othmer, James, and Berman, "Friction of Fluids in Solder-Type Fittings", <u>Transactions of the American Institute of Chemical Engineers</u>, 36: 721-37: 1940.

Purpose.

This investigation was undertaken to determine the friction losses in pipe fittings and valves, correlating the results with the Reynolds number. From the preceding survey it has been perceived that a great deal of work has been conducted on this phase of fluid flow, but the results have varied. Thus it was deemed necessary to check former experimenters and establish the correct results. A comparison with recently published data will be made, and data on several fittings not given in the literature will be presented.

Since straight pipe data is correlated with the Reynolds number, it seemed logical to present losses in fittings in this manner. Thus, in design of piping installations, the friction loss values in equivalent feet of various type fittings can be conveniently read from a graph once the Reynolds number is known.

It was proposed to obtain the data by constructing a series of manometer connections on each side of the fitting to be tested in order to remove the possibility of not obtaining the total loss caused by the fitting. It was believed that a more reliable determination could be made in this way.

Theory

The friction loss of a fluid flowing through a pipe is only a special case of a general law of the resistance between a solid and fluid in relative motion. If a solid body of any shape be immersed in a fluid stream and the velocity of the fluid past the body is small in comparison to the velocity of sound, it has been found experimentally that the resisting force depends only on the roughness, size and shape of the solid and on the velocity, density, and vicosity of the fluid. It can thus be shown that:

$$F/A = pu^2/g \; \Phi' \, . \, Dup/\mu \qquad (1)$$

where

F = the total resisting force.

A = the area of the body.

u = the velocity of the fluid past the body.

p = the density of the fluid.

D = the diameter.

μ = the viscosity of the fluid.

g = the acceleration of gravity.

Φ' = some function whose precise form must be determined for each specific case.

In the particular case of a fluid flowing through a circular pipe of length L, the total force resisting flow must equal the product of the area of contact between the fluid and the pipe wall, and the F/A of equation (1). Then the pressure drop will equal this product divided by the cross-sectional area of the pipe, since pressure is measured in force per unit area. (14)

$$\Delta P_f = F/A(4\ L\pi D/\pi D^2) = 4\ pu^2L/gD\ .\ \Phi'\ (Dup/\mu) \qquad (2)$$

or

$$\Delta P_f D/u^2Lp = \Phi(Dup/\mu = \Delta H_f D/u^2L \qquad (3)$$

$$\Phi = 4\ \Phi'/g$$

where

ΔP_f = pressure drop due to friction in pounds per square foot.

F/A = resisting force in foot-pounds per square foot of contact area.

L = length of pipe in feet.

D = inside diameter of pipe in feet.

p = density of fluid in pounds per square foot.

u = average velocity of fluid in feet per second.

μ = viscosity of fluid in English units.

g = acceleration of gravity.

ΔH_f = loss in head due to friction in feet.

The latter equation was used for the plot of the straight pipe data in this paper.

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(14) Badger and McCabe, op. cit., p. 35.

In fluid flow, there are two forms of fluid motion known as viscous flow and turbulent flow. Viscous flow occurs at low velocities, the individual particles of water flowing in parallel straight lines. Turbulent flow manifests itself at the high velocities, the individual particles of water flowing in an erratic manner. The velocity at which the flow changes from viscous to turbulent flow is known as the critical velocity.

The Reynolds number ($Du\rho/\mu$), indicated on the previous pages, is of importance in fluid flow, because it correlates the factors affecting flow. When the Reynolds number is over 4,000, the flow is always turbulent, and when below 2,100, the flow is always viscous. The critical region is found between these values. This investigation was concerned with the turbulent region of flow in determining the friction losses in fittings and valves. The symbol for the Reynolds number used in this paper is "Re".

EQUIPMENT

The equipment used in obtaining the friction losses in standard one-inch galvanized iron pipe fittings consisted essentially of a centrifugal pump, a means for introducing water under city pressure, calibrated orifices for measuring the low rates of flow, a calibrated receiving tank for measuring the high rates of flow, a line in which the fittings were inserted for test, a stretch of straight pipe, manometers for measuring the pressure drops, and a valve situated at the end of the lines for controlling the rates of flow.

The testing equipment was situated on the balcony of the unit operations laboratory as shown in the photographs. Only standard one-inch galvanized iron pipe fittings and one-inch brass globe and gate valves were tested. Galvanized pipe and fittings were used in order to prevent rusting. The fittings tested were:

(1) a ninety degree elbow

(2) a forty-five degree elbow.

(3) a tee, (water leaving branch).

(4) a tee, (water entering branch).

(5) a cross, (water leaving branch).

(6) a Y, (water leaving branch).

No data was found in the literature on fittings (5) and (6).

The centrifugal pump, shown in Figure 3, was operated

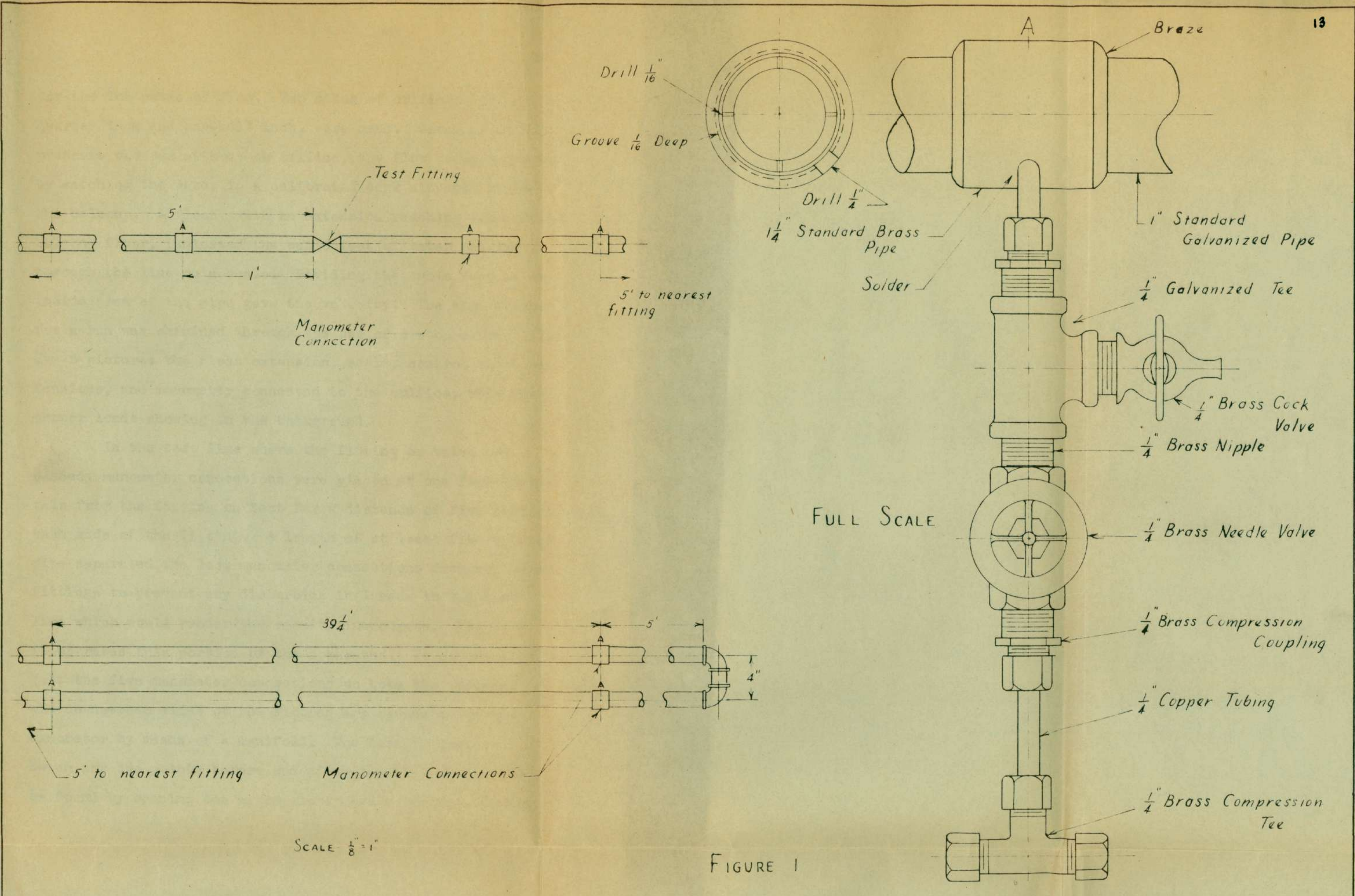

Figure I

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Friction Loss Set-Up

Date - 4/7/42 Submitted By - E. D. Ermenc for the low rates of flow. Two sizes of orifices, one-quarter inch and one-half inch, were used. Water under city pressure was run without an orifice, the flow being measured by catching the water in a calibrated tank situated below the balcony. A float, with an extension reaching through the balcony floor, indicated the cubic feet of water passing through the line on a scale. Dividing the cubic feet by the inside area of the pipe gave the velocity. The time elapsed for a run was obtained through the use of a stop watch. Figure 5 pictures the float extension, scale, control valve extensions, and manometer connected to the orifice, with the copper leads showing in the background.

In the test line where the fitting or valve was placed, manometer connections were placed at one foot intervals from the fitting on test for a distance of five feet on each side of the fitting. A length of at least five feet of pipe separated the last manometer connections from any other fittings to prevent any disturbing influence in the test line which would render the results inaccurate. Figure 2 illustrates this portion of the apparatus. It can be seen that the five manometer connections on both the upstream and downstream sides of the fitting are connected to the manometer by means of a manifold. The loss in head between any two points before and after the fitting can thus be found by opening the appropriate needle valves. Figure

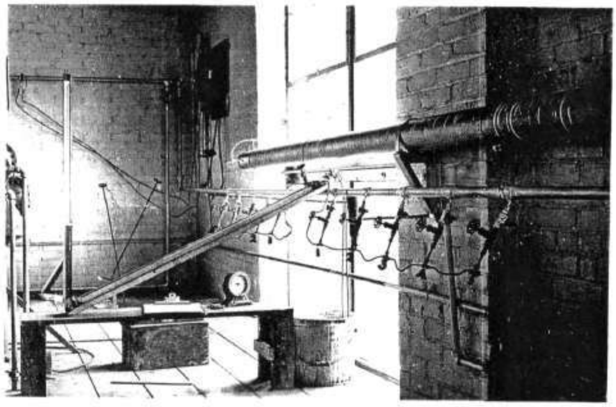

Figure 2. Test Section

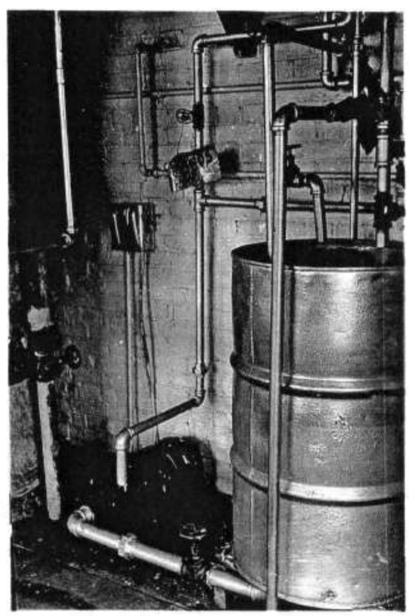

Figure 3. Centrifugal Pump and Tank

1 shows a detail of this arrangement. The cock valve was used to flush out the air, and valves on the manometer enabled a flushing to be made there too. Inclined differential U-tube type manometers were the pressure loss measuring instruments, having mercury for the high friction losses and carbon tetrachloride for the low friction losses.

The construction of the piezometer connection to the pipe is also depicted in Figure 1. After drilling the four one-sixteenth inch holes indicated on the drawing, the inside of the pipe was freed of burrs caused by drilling by the adaptation of a reamer machined to fit the pipe exactly. This precautionary measure was adopted to prevent any disturbance in the flow.

The straight pipe section shown in Figure 4 ran the length of the laboratory. It was necessary to insert four couplings in the length of 78.5 feet, but their contribution to the friction loss was considered to be negligible. The same type of piezometric connections were used as in the test section for fittings.

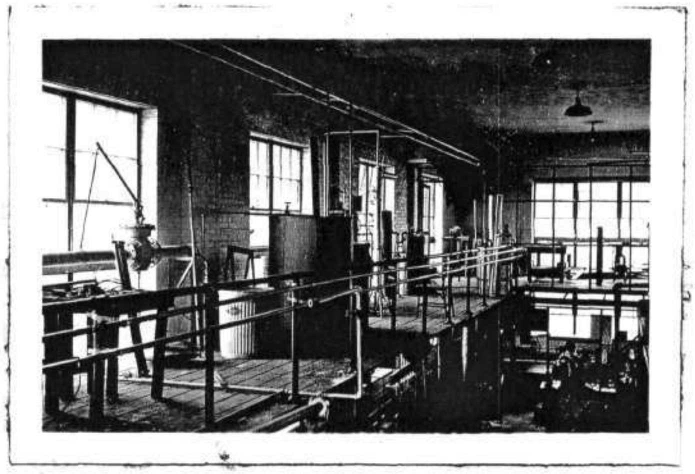

Figure 4. Straight Pipe Section

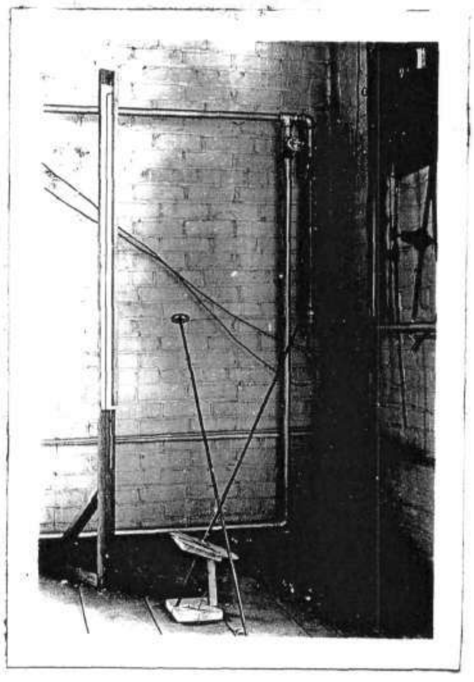

Figure 5. Control Section

PROCEDURE

Water was run from the main into the tank feeding the centrifugal pump. A constant head was maintained on the pump through the use of an overflow pipe on the tank. The water was pumped through the lines until a constant temperature was attained. The control valve was then adjusted and the velocity obtained from the reading of the manometer attached to the orifice. All of the needle valves attached to the manifold leading to the manometer for measuring the friction drop across the test fitting were opened. The cock valves at the manometer were then opened, and the air was flushed out. Similarly, the cock valves at the pipe were flushed. All valves were then closed.

Referring to Figure 2, the pair of needle valves marked 1-1 were opened and the reading of the manometer taken. It is readily seen that the loss across two feet of pipe plus the fitting was revealed. In the same way, the losses across 2-2 through 5-5 were obtained. Losses for various velocities were found, but due to the human error involved in reading the manometers, numerous check runs were made, as is evident from the tabulated data.

In the measurement of lengths of pipe, the "no length" concept of fittings initiated by Giesecke, Reming, and Knudson (15) was used. In short, the fittings were assumed to

(15) Giesecke, Reming, and Knudson, loc. cit.

add no length to the pipe line, since, in calculating the pressure drop, the loss due to the fitting is added to the drop in the line. Distances were measured from the ends of the fitting in question.

The results obtained were converted into friction loss in feet of water and plotted against the feet of pipe. The resulting straight line was extrapolated past the zero point until it intersected the negative abscissa. The point of intersection gave the equivalent length of the fitting in feet directly. The zero point or intersection of the line with the ordinate gave the friction loss in feet of water incurred by the fitting. An illustration is shown in the appendix. The values found by the intersection of the negative abscissa were plotted against the Reynolds numbers as shown on the pages following. As a check, the losses in feet of water were converted into equivalent lengths through the use of the straight pipe data on Figure 6. Both graphical and calculated results are indicated in the tabulated data.

Table I

Straight Pipe

D=1.04"   L=79.6'

°F	u	Re	ΔH_f	$\frac{\Delta H_f D}{u^2 L}$
60	8.44	60,800	30.50	0.000468
59	7.60	53,900	26.50	0.000499
60	6.57	47,300	19.70	0.000498
59	6.29	44,600	17.77	0.000489
59	5.63	40,000	15.00	0.000515
59	5.21	37,000	13.29	0.000534
59	4.86	31,100	11.62	0.000538
59	3.90	27,700	7.22	0.000518
59	3.28	23,300	5.15	0.000522
59	2.75	19,500	3.69	0.000531
59	2.11	15,000	2.27	0.000556
59	1.83	13,000	1.75	0.000570
59	1.55	11,000	1.27	0.000578
60	1.12	8,060	0.70	0.000606
60	0.70	5,050	0.32	0.000713
58	8.67	60,800	34.04	0.000493
58	8.11	56,900	30.72	0.000507
59	7.65	54,300	25.86	0.000482
59	7.17	51,000	25.40	0.000539
60	6.41	46,100	18.44	0.000489
59	5.73	40,700	15.07	0.000499
59	5.11	36,300	11.85	0.000495
59	4.52	32,100	9.59	0.000512
58	4.20	29,400	8.43	0.000522
58	3.65	25,500	6.38	0.000522
59	3.01	21,400	4.43	0.000534
59	2.29	16,300	2.61	0.000543
59	2.03	14,400	2.13	0.000561
59	1.78	12,600	1.66	0.000574
60	1.44	10,400	1.15	0.000606
60	0.99	7,190	0.56	0.000625
59	8.51	60,500	33.07	0.000498
58	8.12	56,900	30.63	0.000506
58	6.95	49,400	23.42	0.000529
59	6.40	45,400	18.66	0.000496
59	5.45	38,700	14.49	0.000532
58	4.76	33,500	10.34	0.000500
58	4.20	29,400	8.40	0.000519
59	3.70	26,300	6.58	0.000524

Table I (cont.)

^{o}F	u	Re	ΔH_f	$\frac{\Delta H_f D}{u^2 L}$
59	2.47	17,500	3.09	0.000553
59	2.26	16,100	2.57	0.000550
59	2.04	14,500	2.13	0.000560
59	1.72	12,200	1.53	0.000565
60	1.35	9,730	0.98	0.000587
60	0.70	5,040	0.31	0.000698
58	8.01	56,900	26.54	0.000452
60	7.62	54,900	27.94	0.000524
59	6.44	45,700	18.61	0.000489
59	5.65	40,100	14.44	0.000490
59	5.34	38,000	13.50	0.000516
58	5.02	35,100	11.42	0.000495
58	4.36	30,500	9.03	0.000515
59	3.90	27,700	7.20	0.000523
59	3.21	22,800	5.03	0.000540
59	2.25	16,000	2.50	0.000539
59	2.02	14,300	2.13	0.000570
59	1.79	12,700	1.67	0.000567
59	1.51	10,700	1.22	0.000585
59	1.20	8,530	0.81	0.000614
60	0.73	5,250	0.32	0.000657
59	5.02	35,600	11.31	0.000490
59	4.47	31,700	9.09	0.000495
59	3.90	27,700	7.12	0.000511
59	3.30	23,400	5.16	0.000516
59	2.30	16,300	2.64	0.000544
59	1.99	14,100	2.03	0.000559
59	1.70	12,100	1.57	0.000592
59	1.55	11,000	1.25	0.000568
60	1.22	8,780	0.79	0.000579
60	0.76	5,540	0.32	0.000605
59	7.10	50,400	22.40	0.000486
59	6.75	47,900	20.40	0.000491
58	5.11	35,800	11.92	0.000498
58	4.65	32,600	10.25	0.000518
59	2.55	18,100	3.20	0.000537
59	2.30	16,300	2.60	0.000537
59	2.12	15,000	2.10	0.000529
60	1.86	13,400	1.65	0.000536
60	1.60	11,500	1.25	0.000550
60	1.23	8,860	0.78	0.000574
60	0.75	5,480	0.31	0.000621

Table II

45^o Elbow

^oF	u	Equivalent Length Graph	Equivalent Length Calc.	ΔH_f	Re
59	8.98	1.60	1.61	0.70	63,700
59	8.16	1.60	1.61	0.59	57,900
59	5.14	1.60	1.59	0.24	36,500
59	4.20	1.70	1.64	0.17	29,800
60	2.95	1.55	1.66	0.09	21,200
60	2.59	1.55	1.49	0.06	18,600
60	2.32	1.45	1.40	0.05	16,700
60	1.92	1.45	1.38	0.03	13,700
60	1.57	1.50	1.45	0.02	11,300
60	1.13	1.30	1.20	0.01	8,100
59	8.65	1.55	1.60	0.65	61,400
58	8.20	1.70	1.73	0.64	57,400
59	7.03	1.70	1.71	0.47	49,900
60	5.65	1.60	1.45	0.26	40,600
59	5.22	1.65	1.59	0.25	37,100
59	3.95	1.60	1.52	0.14	28,000
59	3.22	1.55	1.58	0.10	22,700
59	2.35	1.50	1.46	0.05	16,700
59	2.06	1.30	1.31	0.04	14,500
59	1.35	1.15	1.13	0.01	9,730
60	0.76	1.55	1.68	0.01	5,470
59	7.68	1.70	1.68	0.55	54,500
59	6.74	1.55	1.58	0.40	47,800
59	5.75	1.50	1.40	0.26	40,800
59	3.05	1.50	1.40	0.08	21,600
60	2.01	1.30	1.26	0.03	14,400
60	1.77	1.20	1.25	0.03	12,800
60	1.12	1.15	1.22	0.01	8,100
61	0.77	2.35	2.04	0.01	5,550
59	6.15	1.60	1.64	0.35	42,600
59	5.20	1.60	1.48	0.23	36,900
59	4.30	1.60	1.47	0.16	30,500
59	3.05	1.50	1.39	0.08	21,600
60	2.04	1.30	1.34	0.04	14,600
60	1.73	1.20	1.35	0.03	12,400
60	1.39	1.45	1.38	0.02	10,100
61	0.77	2.40	2.03	0.01	5,650
59	5.75	1.65	1.56	0.29	40,800
59	4.85	1.50	1.48	0.20	34,400

Table II (cont.)

^{o}F	u	Equivalent Length Graph	Equivalent Length Calc.	ΔH_f	Re
59	3.89	1.55	1.56	0.14	27,500
59	3.26	1.65	1.55	0.10	23,100
59	2.07	1.25	1.23	0.03	14,900
59	1.74	1.30	1.32	0.03	12,300
60	1.41	1.30	1.28	0.02	10,000
60	1.02	1.20	1.21	0.01	7,350
60	0.88	1.80	1.67	0.01	6,480
60	6.00	1.80	1.82	0.37	43,200
60	4.75	1.50	1.54	0.20	34,200
59	4.35	1.70	1.62	0.18	30,900
59	1.70	1.30	1.29	0.03	12,100
60	1.55	1.25	1.29	0.02	11,200
60	1.42	1.35	1.26	0.02	10,000
60	1.13	1.80	1.67	0.02	8,100
61	0.95	1.65	1.51	0.01	6,600
61	0.68	2.40	2.15	0.01	4,930

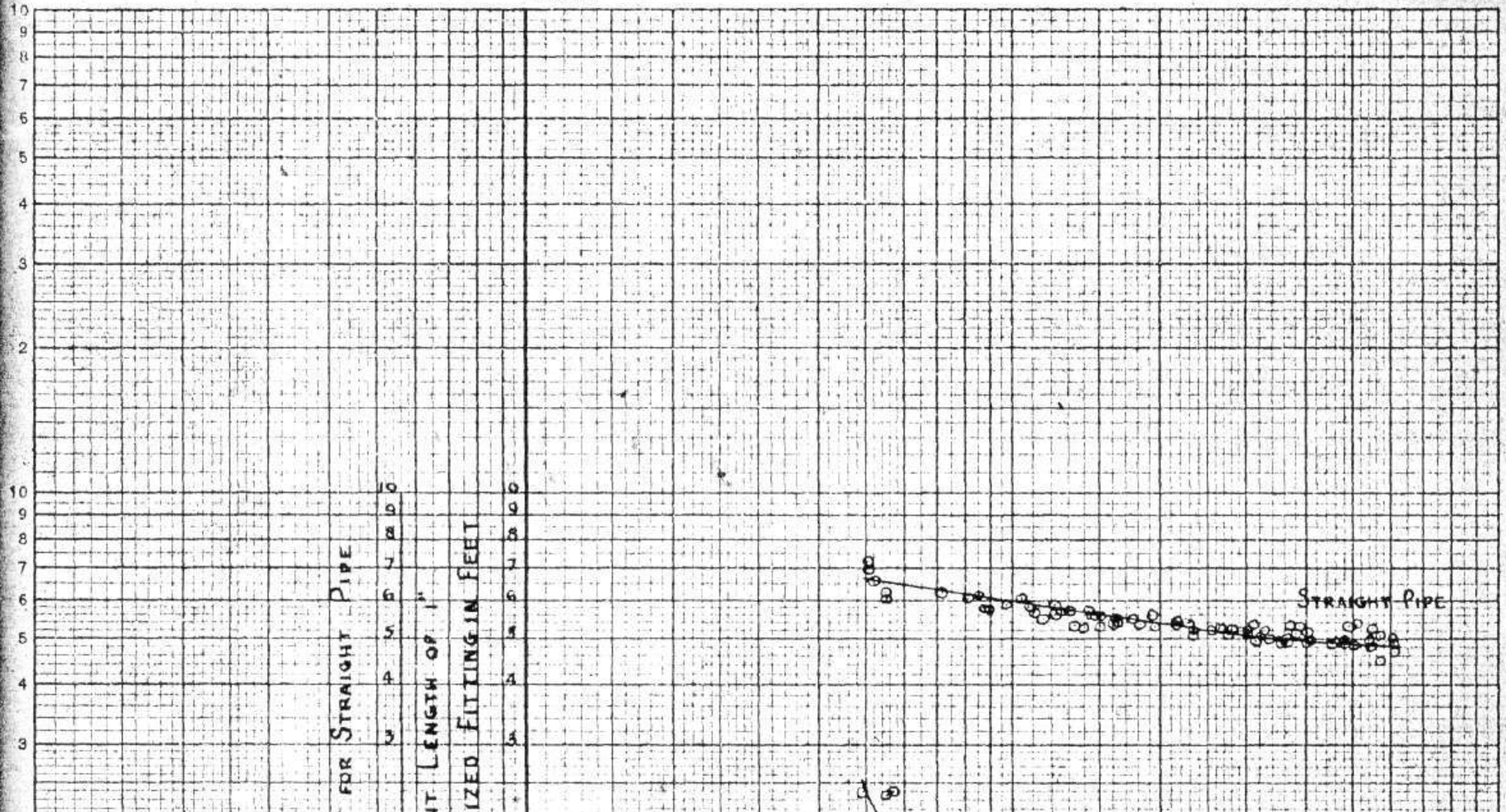

Figure 6 — Friction Loss Chart of Straight Pipe and 45° Elbow

DISCUSSION

Curves

The curves obtained are very similar in form for the fittings, except in the case of the tee where the water enters the branch. In the high range of Reynolds numbers, the equivalent length is practically the same as that for the tee where the water leaves the branch. However, in the low range of Reynolds numbers, the two curves diverge from each other as is readily seen from Figures 8 and 9.

Comparing the other graphs, the curves of the forty-five degree elbow and ninety degree elbow indicate that the loss in the forty-five degree elbow is approximately one-half the loss in the ninety degree elbow. The loss in the cross is very similar, over the total range of Reynolds numbers, to the tee where the fluid leaves the branch, and the Y shows a loss approximately equal to the loss in the ninety degree elbow. Figures 7, 8, 10, and 11 illustrate the above. The graphs depict the conclusion that the friction loss is dependent upon the velocity.

The possibility of error is predominantly on the human side in the reading of the manometer. The lower velocities presented few difficulties, but at the higher velocities the variation observed in the manometer readings, due to greater turbulence, made an average reading necessary. This was especially true in the determination of losses in the globe valve.

Table III

Globe Valve

Equivalent Length

°F	u	Graph	Calc.	ΔH_f	Re
48	5.75	19.00	16.50	3.10	34,500
48	5.56	19.90	16.98	3.02	33,400
48	4.89	17.50	16.42	2.33	29,400
48	4.75	19.60	16.90	2.27	28,500
48	4.10	18.80	17.40	1.75	24,600
48	4.02	18.40	17.05	1.67	24,000
49	2.95	19.60	16.48	0.90	18,000
48	2.98	18.50	16.98	0.96	17,900
47	2.10	15.60	15.00	0.44	12,400
47	1.86	15.20	14.55	0.34	11,100
47	1.60	14.30	13.90	0.25	9,500
47	1.25	13.80	13.00	0.15	7,430
47	0.78	12.80	11.00	0.05	4,610
48	5.62	18.40	17.00	3.10	33,700
48	5.35	18.80	16.50	2.75	32,000
48	5.00	17.80	17.00	2.50	30,000
48	4.40	19.80	16.75	1.95	26,400
48	4.00	19.80	16.85	1.63	24,000
48	3.28	18.00	17.90	1.20	19,700
48	2.98	19.40	16.55	0.93	17,900
46	2.10	15.30	15.08	0.44	12,300
46	1.85	14.80	14.70	0.34	10,800
46	1.58	15.00	14.00	0.25	9,250
47	1.22	13.60	13.11	0.14	7,250
48	0.67	11.70	10.55	0.04	3,990
48	5.72	18.20	16.92	3.19	34,300
48	4.98	18.30	17.20	2.51	29,800
48	3.94	17.90	17.25	1.62	23,600
48	3.01	19.20	17.70	1.01	18,000
47	1.93	17.00	15.45	0.39	11,500
47	1.65	14.60	14.35	0.27	9,900
48	1.34	12.40	13.70	0.18	8,050
48	0.98	15.40	14.10	0.10	5,880
47	5.72	17.80	16.92	3.18	33,800
47	5.15	17.40	16.75	2.61	30,600
47	4.20	19.00	17.00	1.80	25,000
47	3.18	17.80	16.85	1.06	18,900
47	1.97	15.40	14.77	0.39	11,800
47	1.72	14.80	14.22	0.29	10,200

Table III (Cont.)

Equivalent Length

°F	u	Graph	Calc.	ΔH_f	Re
47	1.44	14.00	13.62	0.20	8,550
47	1.03	11.80	11.75	0.09	6,120
47	5.55	18.20	16.52	2.95	32,900
47	4.70	19.00	16.81	2.22	28,000
47	3.80	18.60	16.40	1.45	22,600
47	3.35	16.80	16.22	1.13	19,900
47	1.40	14.20	14.05	0.19	8,300
47	1.03	13.20	12.50	0.10	6,100
47	5.82	18.80	17.45	3.41	34,600
47	4.70	19.40	16.20	2.20	28,000
47	3.94	16.40	16.00	1.50	23,400
47	3.01	20.00	17.50	1.00	17,900

Table IV

90° Elbow

Equivalent Length

°F	u	Graph	Calc.	ΔH_f	Re
50	9.40	2.85	2.77	1.35	56,800
49	8.45	2.95	2.82	1.12	50,100
49	8.01	2.90	2.85	1.02	48,000
51	7.25	2.90	2.86	0.85	43,500
51	5.75	2.50	2.41	0.46	34,500
47	5.25	2.40	2.23	0.36	30,800
47	4.72	2.40	2.12	0.28	27,700
47	4.10	2.30	2.08	0.21	24,100
47	3.30	2.20	2.06	0.14	19,400
47	2.50	2.10	1.99	0.08	14,700
48	2.40	2.35	2.24	0.08	14,100
48	2.07	2.30	2.15	0.06	12,100
48	1.73	2.30	2.17	0.04	10,100
48	1.40	2.65	2.54	0.04	8,210
48	1.20	2.85	2.64	0.03	7,040
48	0.89	3.30	2.76	0.02	5,250
49	9.00	2.80	2.81	1.26	54,000
49	8.59	2.75	2.70	1.10	51,600
50	8.06	2.65	2.61	0.95	48,400
50	7.29	2.80	2.80	0.84	43,700
51	5.92	2.60	2.72	0.55	35,500
46	5.25	2.60	2.41	0.39	30,700
46	4.65	2.45	2.26	0.29	27,200
46	4.02	2.40	2.23	0.22	23,400
46	3.40	2.40	2.22	0.16	19,900
47	2.80	2.50	2.38	0.12	16,350
47	2.35	2.30	2.08	0.08	13,700
47	2.06	2.40	2.35	0.07	12,000
48	1.70	2.50	2.32	0.05	10,200
48	1.38	2.40	2.31	0.03	8,240
48	1.01	3.40	2.94	0.02	6,000
48	9.40	2.85	2.77	1.35	56,400
49	8.26	2.90	3.15	1.19	49,600
49	6.98	2.85	2.88	0.79	41,900
50	6.11	2.80	2.82	0.61	37,0[illegible]
47	5.85	2.40	2.29	0.45	35,[illegible]
46	5.38	2.20	2.06	0.35	30,[illegible]
46	4.60	2.60	2.44	0.31	26,[illegible]
48	4.06	2.45	2.30	0.23	24,[illegible]
48	3.50	2.15	1.98	0.15	21,[illegible]

Table IV (cont.)

^{o}F	u	Equivalent Length Graph	Equivalent Length Calc.	ΔH_f	Re
48	2.73	2.20	2.10	0.10	16,300
47	2.38	2.45	2.34	0.09	14,300
47	2.03	2.30	2.23	0.06	11,900
47	1.75	2.25	2.24	0.05	10,450
47	1.46	2.50	2.33	0.04	8,560
47	1.11	3.20	2.92	0.03	6,450
47	0.85	4.40	4.03	0.02	5,000
48	5.82	2.35	2.26	0.44	34,900
48	5.22	2.60	2.38	0.38	31,300
48	4.65	2.25	2.11	0.27	27,900
48	4.05	2.30	2.13	0.21	24,300
48	3.28	2.05	1.94	0.13	19,800
48	2.35	2.45	2.32	0.08	14,100
49	2.05	2.40	2.34	0.07	12,300
50	1.17	2.85	2.60	0.03	7,250
50	0.83	3.05	3.00	0.02	5,200
46	5.85	2.50	2.39	0.47	34,400
44	5.30	2.45	2.36	0.39	30,000
44	4.85	2.40	2.28	0.32	27,400
44	4.35	2.40	2.26	0.26	25,100
44	3.78	2.70	2.50	0.22	21,200
45	2.87	2.40	2.28	0.12	16,400
45	2.34	2.10	2.08	0.08	13,400
46	1.98	2.10	2.10	0.06	11,300
46	1.77	2.40	2.34	0.05	10,100
46	1.47	2.60	2.42	0.04	8,500
47	1.13	3.30	3.09	0.03	6,400
47	0.87	4.30	3.99	0.20	4,900
44	5.85	2.50	2.48	0.48	33,400
44	5.25	2.70	2.50	0.41	29,900
45	4.47	2.60	2.87	0.31	25,500
45	3.56	2.70	2.79	0.17	20,300
46	2.73	2.70	2.71	0.11	15,600
46	1.97	2.55	2.43	0.06	11,470
47	1.86	2.60	2.48	0.06	10,780
47	1.63	3.00	2.80	0.05	9,510
47	1.40	3.20	2.90	0.04	8,100
47	1.15	3.40	3.00	0.03	6,650
47	0.72	4.00	4.43	0.02	4,110
47	5.85	2.30	2.18	0.43	34,400

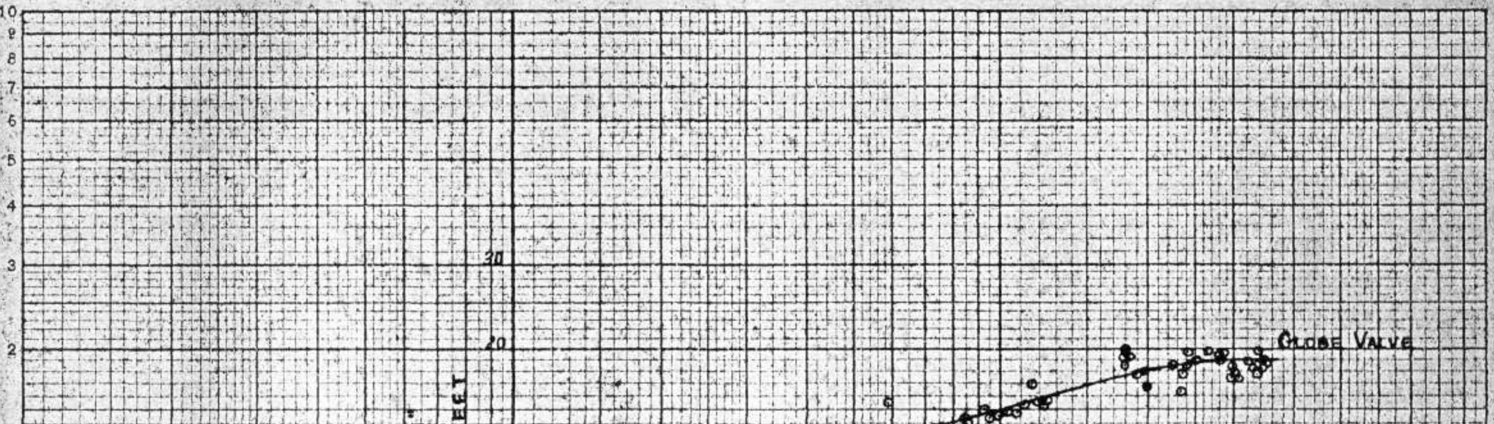

FIGURE 7 — FRICTION LOSS CHART OF GLOBE VALVE AND 90° ELBOW

Table V

Tee (Water entering branch)

Equivalent Length

^{o}F	u	Graph	Calc.	ΔH_f	Re
56	9.05	4.00	3.94	1.75	61,500
56	8.36	3.80	3.86	1.49	56,900
57	6.87	3.50	3.58	0.92	46,700
58	5.92	3.10	3.34	0.66	41,500
53	5.76	3.60	3.32	0.63	37,400
53	4.70	3.60	3.23	0.42	30,400
53	3.30	3.15	3.13	0.21	21,400
59	2.48	3.00	2.99	0.12	17,600
59	2.20	3.25	3.05	0.10	15,600
59	1.90	2.75	2.71	0.06	13,500
59	1.55	2.40	2.62	0.04	11,000
60	1.14	2.50	2.38	0.02	8,200
60	0.78	1.80	1.64	0.01	5,580
57	8.43	3.65	3.72	1.67	62,800
57	7.75	4.00	3.91	1.52	58,200
57	7.23	3.65	3.82	1.27	53,500
58	6.80	3.80	3.83	0.99	47,600
53	6.70	3.40	3.54	0.90	43,500
53	5.88	3.60	3.62	0.72	38,100
53	5.22	3.25	3.19	0.50	33,800
53	4.05	3.25	3.18	0.31	26,200
53	3.26	3.10	3.04	0.20	21,000
60	2.54	3.20	3.07	0.13	18,300
60	2.20	2.85	2.80	0.09	15,800
60	1.73	2.70	2.72	0.05	12,400
59	1.45	2.55	2.31	0.03	10,300
59	1.33	1.95	1.90	0.02	9,400
59	0.93	2.00	1.71	0.01	6,480
56	8.89	3.78	3.86	1.65	60,400
56	8.42	3.50	3.63	1.42	57,400
55	7.86	3.75	3.71	1.27	52,600
56	7.18	4.00	3.82	1.10	44,900
53	5.75	3.70	3.54	0.67	37,200
53	5.14	3.40	3.28	0.50	33,300
53	4.14	3.35	3.22	0.33	26,700
53	3.24	3.15	3.09	0.20	21,400
59	2.64	3.25	3.15	0.14	18,000
59	2.37	2.95	2.92	0.11	16,800
59	2.02	2.80	2.70	0.07	14,300
59	1.71	2.75	2.74	0.05	12,100
59	1.22	2.30	2.17	0.02	8,660
60	0.90	1.85	1.68	0.01	6,440

Table V (cont.)

Equivalent Length

^oF	u	Graph	Calc.	ΔH_f	Re
52	5.80	3.75	3.47	0.67	37,600
53	4.70	3.65	3.31	0.43	30,800
53	5.22	3.25	3.18	0.50	33,800
53	4.21	3.65	3.34	0.35	27,200
53	3.38	3.40	3.28	0.23	22,200
59	2.38	3.30	3.13	0.11	16,900
59	2.10	2.85	2.70	0.08	14,700
59	1.77	2.60	2.48	0.05	12,500
60	1.06	2.00	1.76	0.01	7,600
52	5.75	3.60	3.36	0.64	36,600
53	4.96	3.90	3.55	0.51	32,100
59	4.02	3.30	3.19	0.31	28,500
59	3.46	3.20	3.16	0.23	24,600
59	2.76	3.20	3.15	0.15	19,500
60	2.22	3.05	2.93	0.09	15,800
60	1.93	2.70	2.67	0.07	13,800
61	1.58	2.75	2.60	0.04	11,300
60	1.26	2.90	2.28	0.03	9,100
60	0.99	2.15	2.08	0.02	7,140
61	0.65	1.80	1.29	0.01	4,740
59	2.50	3.20	3.09	0.12	17,700
59	2.22	2.90	2.82	0.09	15,800
59	2.06	2.90	2.80	0.08	14,500
59	1.69	2.80	2.80	0.05	11,900

Table VI

Gate Valve

Equivalent Length

°F	u	Graph	Calc.	ΔH_f	Re
48	8.91	0.79	0.73	0.32	53,500
50	7.58	0.72	0.69	0.22	47,000
50	6.85	0.70	0.68	0.18	42,400
49	5.70	0.80	0.75	0.14	34,800
49	4.94	0.60	0.56	0.08	30,100
49	4.89	0.60	0.57	0.08	29,800
49	3.82	0.55	0.57	0.05	25,000
49	3.29	0.55	0.59	0.04	20,000
51	2.10	0.60	0.58	0.02	13,200
51	1.73	0.60	0.57	0.01	10,900
51	1.40	0.45	0.43	0.01	8,780
52	0.88	0.45	0.43	0.003	5,570
49	9.13	0.78	0.70	0.32	55,700
49	7.58	0.80	0.75	0.24	46,300
49	6.20	0.75	0.68	0.15	37,800
49	4.36	0.60	0.53	0.06	26,800
49	3.94	0.60	0.53	0.05	24,000
49	3.30	0.50	0.44	0.03	20,200
49	3.50	0.55	0.53	0.04	21,300
50	2.07	0.65	0.59	0.02	13,500
51	2.04	0.50	0.46	0.01	12,800
51	1.72	0.55	0.50	0.01	10,800
51	1.33	0.60	0.54	0.01	8,300
47	8.60	0.75	0.73	0.30	50,900
50	6.98	0.78	0.73	0.20	42,600
49	5.85	0.60	0.56	0.11	36,300
52	4.47	0.60	0.59	0.07	28,500
52	3.90	0.60	0.55	0.05	24,800
52	3.30	0.50	0.45	0.03	21,100
52	2.65	0.60	0.33	0.02	16,500
53	2.02	0.55	0.51	0.01	13,100
54	1.15	0.45	0.44	0.004	7,450
54	0.89	0.45	0.42	0.003	5,750
49	8.96	0.80	0.75	0.33	54,600
48	6.58	0.70	0.65	0.16	39,500
48	5.82	0.60	0.61	0.12	34,900
47	3.61	0.55	0.74	0.06	21,200
46	2.58	0.55	0.50	0.02	15,100
47	2.23	0.58	0.54	0.02	13,300
46	1.81	0.55	0.53	0.01	10,500
51	1.42	0.55	0.54	0.008	8,900
52	1.10	0.40	0.38	0.003	6,800

Table VI (cont.)

Equivalent Length

°F	u	Graph	Calc.	ΔH_f	Re
46	8.81	0.78	0.73	0.31	52,200
49	5.85	0.70	0.66	0.13	35,700
49	4.20	0.60	0.57	0.06	25,600
53	2.66	0.50	0.48	0.02	17,200
53	2.37	0.60	0.55	0.02	15,400
53	2.05	0.50	0.48	0.01	13,300
51	1.59	0.50	0.48	0.01	9,920
52	1.18	0.50	0.50	0.005	7,520
51	2.69	0.55	0.53	0.02	16,900
51	2.36	0.65	0.60	0.02	14,700

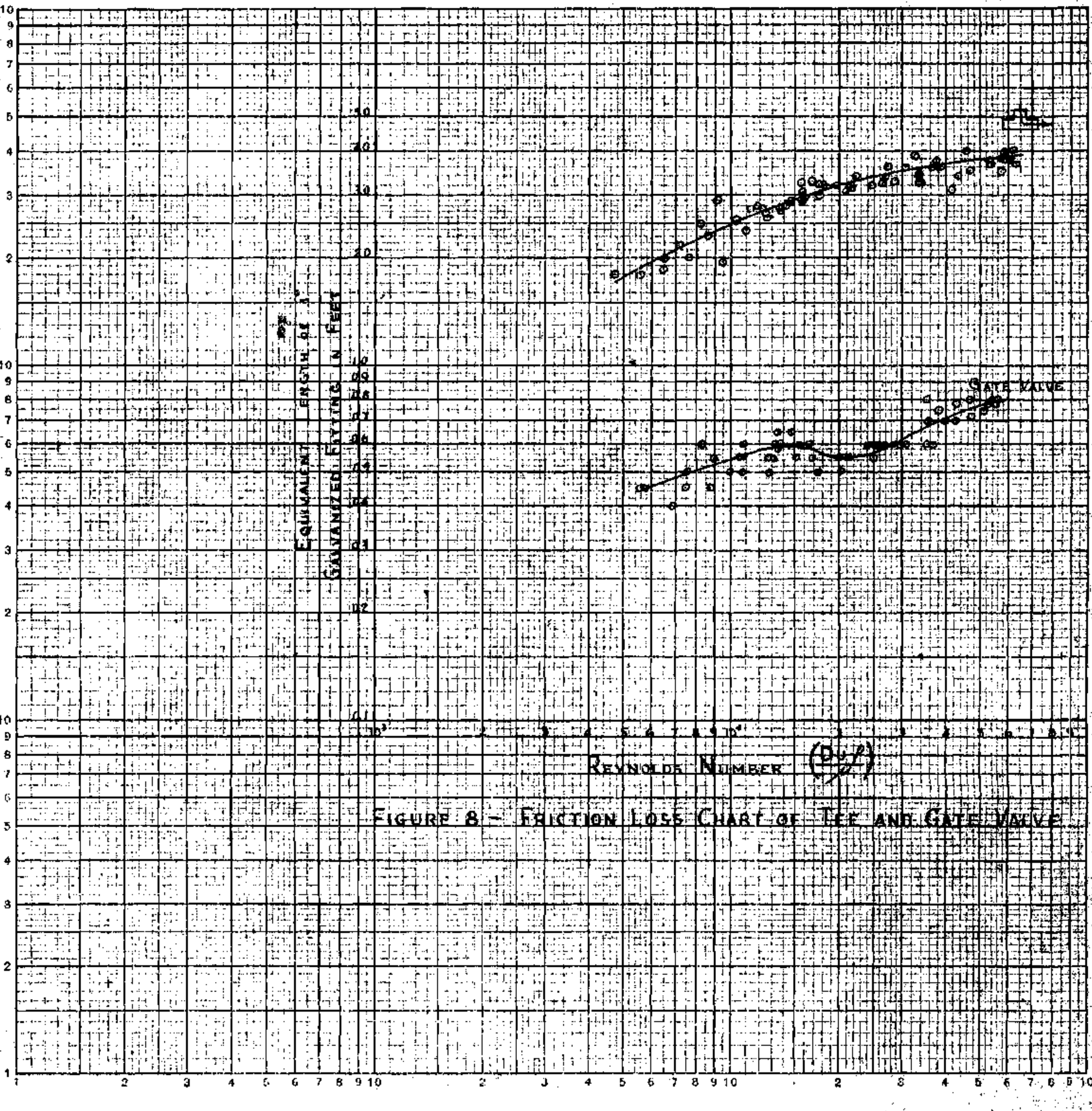

Figure 8 – Friction Loss Chart of Tee and Gate Valve

Table VII

Tee (Water leaving branch)

^{o}F	u	Equivalent Length Graph	Equivalent Length Calc.	ΔH_f	Re
50	9.30	3.80	3.82	1.81	57,600
49	8.45	4.05	4.06	1.60	52,300
50	7.29	3.75	3.79	1.13	45,100
50	5.85	3.80	3.80	0.75	36,200
59	4.12	3.15	2.89	0.29	29,200
59	3.38	3.05	2.75	0.19	23,600
59	2.84	2.95	2.65	0.13	20,200
59	2.57	3.10	2.76	0.11	18,200
59	2.24	2.85	2.58	0.08	16,000
59	1.82	3.00	2.54	0.06	12,900
59	1.33	3.05	2.72	0.03	9,450
60	0.60	4.40	3.25	0.01	4,300
50	9.01	3.80	3.76	1.68	55,900
49	7.85	3.70	3.96	1.37	48,000
59	5.13	3.65	2.97	0.45	36,400
59	4.06	3.30	2.35	0.23	28,800
59	2.84	3.30	2.78	0.14	20,200
59	2.53	3.20	2.80	0.11	18,000
59	2.03	2.70	2.50	0.07	14,400
59	1.57	2.80	2.45	0.04	11,200
60	0.82	3.40	2.82	0.01	5,900
50	9.37	3.55	3.72	1.79	57,600
50	8.54	4.00	3.88	1.56	52,800
51	7.25	3.40	3.52	1.04	45,000
59	5.75	3.50	2.80	0.53	40,900
59	5.18	3.70	2.91	0.45	36,700
59	4.70	3.60	2.81	0.36	33,400
59	3.35	2.90	2.35	0.16	23,800
48	2.66	3.15	3.02	0.14	16,000
48	2.45	3.20	3.10	0.12	14,700
48	2.21	3.25	3.08	0.10	13,200
48	2.00	3.20	3.05	0.08	12,000
48	1.72	2.80	2.74	0.06	10,300
49	1.43	2.85	2.68	0.04	8,520
49	1.00	3.60	3.12	0.02	6,000
50	8.98	3.80	3.89	1.73	55,200
50	7.84	4.10	4.16	1.43	48,500
50	6.09	3.50	3.55	0.76	37,700
59	2.28	3.10	2.77	0.09	16,100
59	2.08	2.80	2.55	0.07	15,000
59	1.87	2.95	2.57	0.06	13,300
59	1.48	2.80	2.52	0.04	10,600

Table VII (cont.)

Equivalent Length

^oF	u	Graph	Calc.	ΔH_f	Re
59	1.11	2.65	2.42	0.02	7,890
60	0.80	3.55	2.76	0.16	5,750
50	9.41	3.90	3.89	1.89	58,400
50	7.85	3.75	3.87	1.33	48,600
58	4.12	3.40	3.00	0.30	28,000
59	3.65	3.10	2.88	0.23	25,900
59	3.00	3.05	2.86	0.16	21,400
48	2.32	3.10	2.96	0.11	13,900
48	2.12	3.30	3.08	0.09	12,700
48	1.84	3.20	3.06	0.07	11,000
48	1.58	3.30	3.04	0.05	9,470
48	0.92	3.40	3.08	0.04	8,150
50	8.62	3.90	3.98	1.64	53,500
50	6.91	3.65	3.96	1.07	42,900
48	2.28	3.05	2.86	0.10	13,800
48	1.97	3.25	3.07	0.08	11,900
48	1.73	2.90	2.82	0.06	10,300
48	1.48	2.95	2.79	0.04	8,890
60	1.34	2.95	2.63	0.03	9,650
60	1.32	2.85	2.62	0.03	9,550
60	1.07	2.80	2.56	0.02	7,700
60	1.06	3.15	2.71	0.02	7,550
61	0.75	3.60	2.76	0.01	5,480
61	0.70	3.60	3.11	0.01	5,100

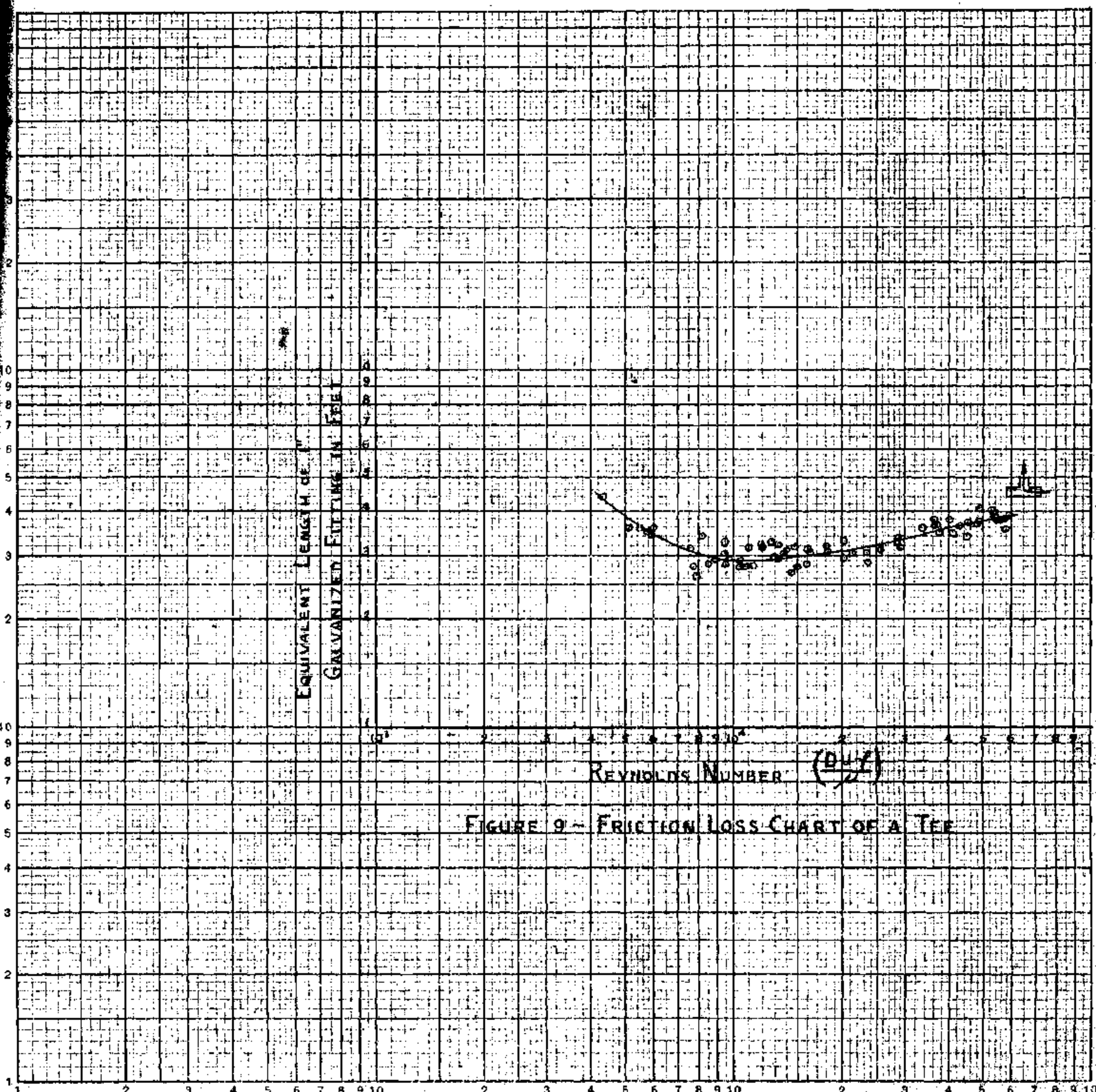
Equivalent Length of 1" Galvanized Fitting in Feet
Reynolds Number $\left(\frac{DU\rho}{\mu}\right)$
Figure 9 - Friction Loss Chart of a Tee

Table VIII

Cross

Equivalent Length

°F	u	Graph	Calc.	ΔH_f	Re
49	8.53	3.65	3.75	1.51	52,000
49	7.74	3.70	3.83	1.28	47,200
50	7.05	3.45	3.60	1.01	43,700
49	5.75	3.60	3.56	0.68	35,000
49	4.92	3.50	3.45	0.49	30,000
49	3.94	3.50	3.54	0.33	24,100
49	2.56	3.20	3.32	0.14	16,300
50	2.28	3.00	3.03	0.10	14,100
50	2.02	2.75	2.84	0.08	12,600
50	1.72	2.90	2.94	0.06	10,600
51	1.37	3.20	3.03	0.04	8,500
51	0.87	4.00	3.81	0.02	6,020
49	9.00	3.85	3.90	1.74	54,800
49	8.42	3.50	3.69	1.45	51,300
50	7.73	3.85	3.92	1.30	47,900
50	6.97	3.70	3.76	1.03	43,200
49	5.76	3.60	3.50	0.67	35,200
49	5.09	3.40	3.41	0.52	31,100
49	4.12	3.30	3.34	0.34	25,200
49	2.91	3.40	3.16	0.17	17,800
50	2.33	3.15	3.14	0.11	14,400
50	2.03	3.00	3.04	0.08	12,600
50	1.70	2.90	2.75	0.07	10,500
51	1.34	2.65	2.64	0.03	8,300
51	0.73	5.10	3.85	0.02	4,520
49	9.02	4.00	3.95	1.77	55,000
49	7.73	3.75	3.84	1.28	47,900
50	5.90	3.60	3.54	0.71	36,600
49	5.50	3.75	3.59	0.63	33,600
49	4.90	3.50	3.44	0.49	29,300
49	3.85	3.40	3.34	0.30	23,500
49	2.57	3.40	3.52	0.15	15,600
50	2.29	3.10	3.15	0.11	14,300
50	2.04	2.75	2.76	0.08	12,600
51	1.73	2.95	2.91	0.06	10,800
51	1.45	3.05	2.96	0.04	9,100
51	1.02	3.65	3.26	0.03	6,400
50	8.39	3.95	4.10	1.59	52,000
49	7.05	4.05	3.88	1.08	43,600
49	6.14	3.50	3.32	0.72	37,400

Table VIII (cont)

°F	u	Equivalent Length Graph	Equivalent Length Calc.	ΔH_f	Re
49	5.35	3.90	3.73	0.62	33,300
49	4.47	3.60	3.52	0.42	27,900
49	3.35	3.60	3.59	0.25	20,800
49	2.40	3.00	2.96	0.11	14,700
51	2.28	2.95	2.92	0.10	14,300
51	2.04	3.00	2.90	0.08	12,800
51	1.72	3.50	3.15	0.06	10,800
51	1.42	3.15	2.96	0.04	8,940
51	1.01	4.25	3.85	0.03	6,270
49	9.00	3.50	3.72	1.66	54,800
49	6.73	3.35	3.52	0.90	41,000
49	5.75	3.60	3.46	0.66	35,000
49	5.11	3.50	3.46	0.53	31,200
49	4.42	3.50	3.42	0.40	26,900
49	3.59	3.40	3.28	0.26	21,800
49	2.56	3.20	3.30	0.14	15,700
50	2.38	2.95	3.07	0.11	14,600
50	2.14	2.70	2.77	0.08	13,200
50	1.90	2.55	2.70	0.07	11,800
51	1.65	3.20	2.99	0.06	10,200
51	1.33	3.30	3.01	0.04	8,250
51	0.89	3.90	3.47	0.02	5,520
49	5.79	4.00	3.73	0.72	35,300
49	4.95	3.50	3.48	0.50	30,200
49	3.60	3.35	3.39	0.27	22,100
49	2.60	3.30	3.21	0.14	15,600
51	2.35	3.20	3.09	0.11	14,700
51	2.10	2.95	2.88	0.08	13,200
51	1.82	3.00	2.94	0.07	11,400
51	1.54	3.30	2.95	0.05	9,650
51	1.25	2.90	2.88	0.03	7,650
51	2.27	3.10	3.06	0.10	14,300
51	2.00	3.30	3.23	0.09	12,500
51	1.72	3.75	3.40	0.07	10,800
52	1.41	3.70	3.38	0.05	8,850

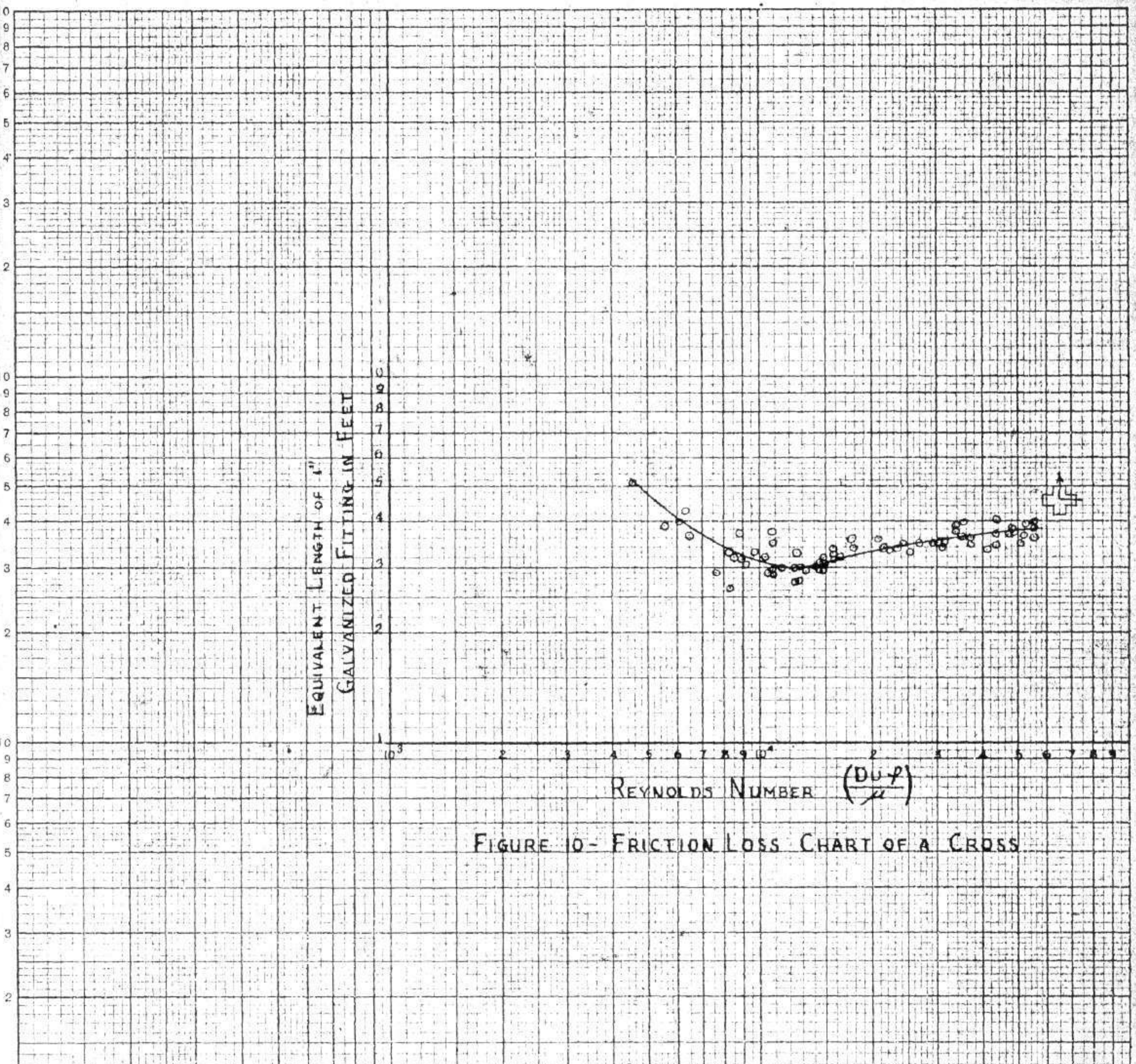

FIGURE 10- FRICTION LOSS CHART OF A CROSS

Table IX

Y

Equivalent Length

^{o}F	u	Graph	Calc.	ΔH_f	Re
48	8.44	2.60	2.80	1.10	50,600
48	7.73	2.70	3.00	1.00	46,400
48	7.42	2.90	2.78	0.86	44,500
48	6.66	2.70	2.82	0.71	40,000
48	6.37	2.60	2.58	0.60	38,200
48	5.65	2.70	2.60	0.48	34,100
48	5.09	2.90	2.62	0.40	30,600
48	4.40	2.30	2.32	0.27	26,500
48	3.93	2.45	2.45	0.23	23,700
48	2.95	2.55	2.54	0.14	17,700
49	2.32	2.35	2.25	0.08	14,100
49	2.02	3.10	2.92	0.08	12,300
49	1.78	3.30	3.08	0.06	10,500
49	1.44	3.50	3.29	0.05	8,700
49	1.02	5.00	4.37	0.04	6,230
47	8.60	2.90	2.88	1.18	51,100
48	7.98	2.80	2.72	0.97	47,900
47	7.41	2.70	2.67	0.83	44,300
48	6.48	2.60	2.71	0.65	38,900
49	5.77	2.45	2.50	0.48	35,200
48	5.58	2.75	2.56	0.46	33,500
48	4.89	2.90	2.68	0.38	29,400
48	3.90	2.75	2.71	0.25	23,400
48	2.97	2.40	2.50	0.13	17,900
48	2.33	2.65	2.48	0.09	14,000
48	2.08	2.60	2.50	0.07	12,500
48	1.84	2.70	2.72	0.06	11,000
48	1.32	3.90	3.37	0.04	7,850
49	0.89	6.00	4.70	0.03	5,400
48	8.86	3.00	3.10	1.35	53,100
48	8.07	2.70	2.70	1.00	48,500
48	6.65	2.90	2.94	0.74	39,900
48	5.66	2.80	2.71	0.50	34,100
48	5.09	2.70	2.62	0.40	30,600
48	4.66	2.45	2.33	0.30	27,400
48	3.88	2.50	2.50	0.23	23,300
48	2.80	2.45	2.59	0.13	16,800
49	2.20	3.00	2.82	0.09	13,400
49	1.98	2.60	2.66	0.07	12,000
49	1.68	3.50	3.13	0.06	10,300

Table IX (cont.)

Equivalent Length

^{o}F	u	Graph	Calc.	ΔH_f	Re
49	1.30	3.45	3.06	0.04	7,950
49	0.88	7.50	5.98	0.04	5,350
48	8.75	2.80	2.92	1.24	52,500
48	7.95	2.80	2.77	0.98	47,700
48	5.55	2.70	2.58	0.46	33,300
48	4.89	2.80	2.54	0.36	29,600
48	4.06	2.70	2.61	0.26	24,300
48	3.01	2.60	2.54	0.15	18,000
49	2.28	2.50	2.32	0.08	13,900
49	2.05	2.60	2.37	0.07	12,500
49	1.78	2.65	2.56	0.06	10,800
49	1.46	3.10	2.75	0.04	8,900
49	1.02	4.00	3.47	0.03	6,200
48	8.30	3.00	2.87	1.18	49,800
48	7.47	2.60	2.70	0.85	44,800
48	5.68	2.60	2.53	0.47	35,200
48	5.11	2.40	2.41	0.37	30,600
48	4.43	2.65	2.58	0.30	26,500
48	3.60	2.30	2.24	0.18	21,600
48	2.60	2.20	2.30	0.10	15,600
49	2.28	2.65	2.47	0.08	14,100
49	2.03	2.45	2.29	0.06	12,300
49	1.72	2.80	2.60	0.05	10,500
49	1.05	5.30	4.52	0.04	6,400
48	5.80	2.60	2.68	0.52	34,800
48	5.46	2.60	2.65	0.46	32,500
48	5.04	2,80	2.68	0.40	30,300
48	4.90	2.60	2.46	0.35	29,400
49	3.56	2.20	2.18	0.17	21,600
48	2.57	2.50	2.82	0.12	15,400
48	5.73	2.90	2.70	0.51	34,300
48	5.70	2.65	2.46	0.46	34,200
48	4.89	2.50	2.47	0.35	29,600
48	4.89	2.60	2.46	0.35	29,600
48	2.95	2.20	2.36	0.13	17,700

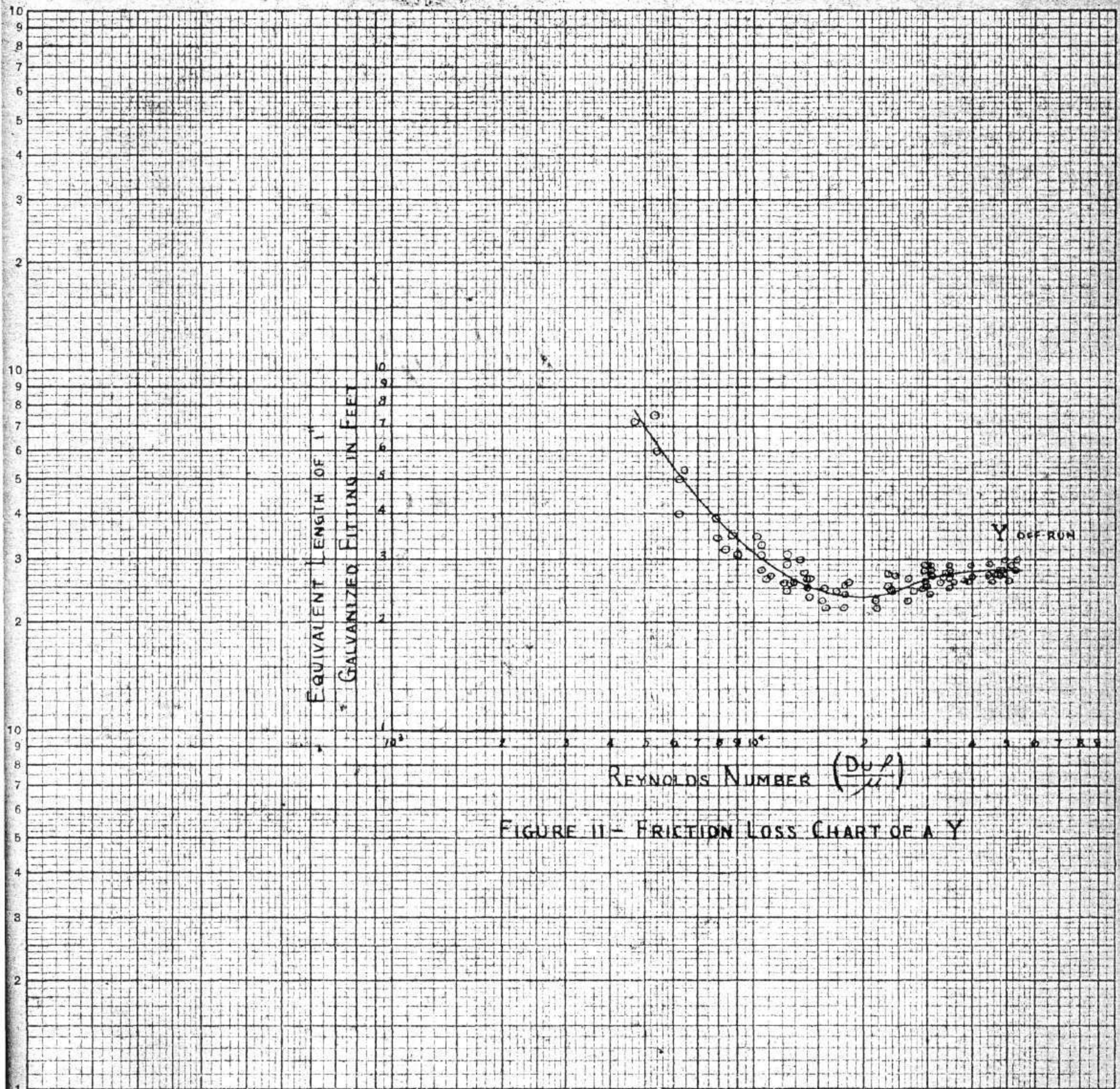

FIGURE 11 - FRICTION LOSS CHART OF A Y

Comparison with Published Values (16)

Table X

Fittings	Published Values (Diameters)	Test Values (Diameters)
Forty-five degree elbows.	15	19
Ninety degree elbows.	32	35
Tee (water leaving branch).	60	46
Tee (water entering branch).	90	46
Gate valve (full-open).	7	9
Globe valve (full-open).	300	240
Cross (off-run)	--	46
Y (off-run)	--	34

The values from this investigation were taken from the maximum points on the graphs at the highest Reynolds numbers. The published values are for turbulent flow as are the test values. The elbows and gate valve check fairly closely, while the test values for the globe valve are somewhat lower than the published values. The losses found in this paper for the tees are lower, and no difference was noted for the tee in the two positions. Values for the cross and Y are new contributions.

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(16) Perry, J. H., loc. cit.

Suggestions for further work and improvement.

More work could be done with this problem on additional fittings. The investigation should extend into the viscous region of flow in order to obtain the losses in fittings in that region also. Different sized pipe fittings should be tested, and a correlation of the friction losses with the diameter made.

Changes in the present apparatus would facilitate testing. A flow meter for the higher velocities would reduce the time necessary for runs. With the set-up at present, it was necessary to empty the tank after one or two velocities were run, which was exceedingly time consuming. Also, an air dome could be installed in the line under city pressure. This would reduce the fluctuation in pressure when other valves were opened in the building. The runs in these tests were made during the night when using city pressure, in order to obtain a relatively constant head. The introduction of an air dome would thus allow tests to be made during the day.

CONCLUSIONS

1. The friction losses in a one-inch tee in which the flow is either directed into or away from the branch is the same, contrary to the literature.

2. The values found for a one-inch forty-five degree elbow, a one-inch ninety degree standard radius elbow, and a one-inch gate valve substantially check the literature, the values in this investigation being slightly higher. The values for the globe valve are somewhat lower than the published values.

3. The friction losses are dependent upon the velocity.

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APPENDIX

Sample Calculations

$$\Delta P = \Delta H(d_1 - d_2)$$

$$\Delta H_r = \Delta H_i(S.G._1 - S.G._2)$$

90° Elbow

Run	Connection Number	Manometer Left	Manometer Right	ΔH_i	ΔH_r
I	1-1	3.70	1.95	1.75	0.80
	2-2	4.10	1.55	2.55	1.17
	3-3	4.45	1.20	3.25	1.49
	4-4	4.80	0.75	4.05	1.85
	5-5	5.15	0.45	4.70	2.15

u = 5.75 ft./sec.

T = 51 °F

Run	Connection Number	Manometer Left	Manometer Right	ΔH_i	ΔH_r
II	1-1	5.20	-0.20	5.00	2.29
	2-2	6.25	0.95	7.20	3.29
	3-3	7.25	2.00	9.25	4.23
	4-4	8.35	3.25	11.60	5.30
	5-5	9.15	4.20	13.45	6.15

u = 9.40 ft./sec.

T = 50 °F

Manometer used --- mercury-water

Inclination of manometer --- $\sin\theta = 0.435$

$$\Delta H_r = \Delta H_i(S.G._1 - S.G._2)\sin\theta$$

$$\Delta H_r = \frac{1.75}{12}(13.6 - 1.0)0.435$$

ΔH_r = 0.80 feet of water

[illegible] data was plotted on the accompanying graph, from wh[illegible]llowing results are obtained:

	I	II
[illegible]alent Length (ft.)	2.55	2.75
[illegible]eet of water)	0.45	1.33

[illegible] obtained by similar methods.

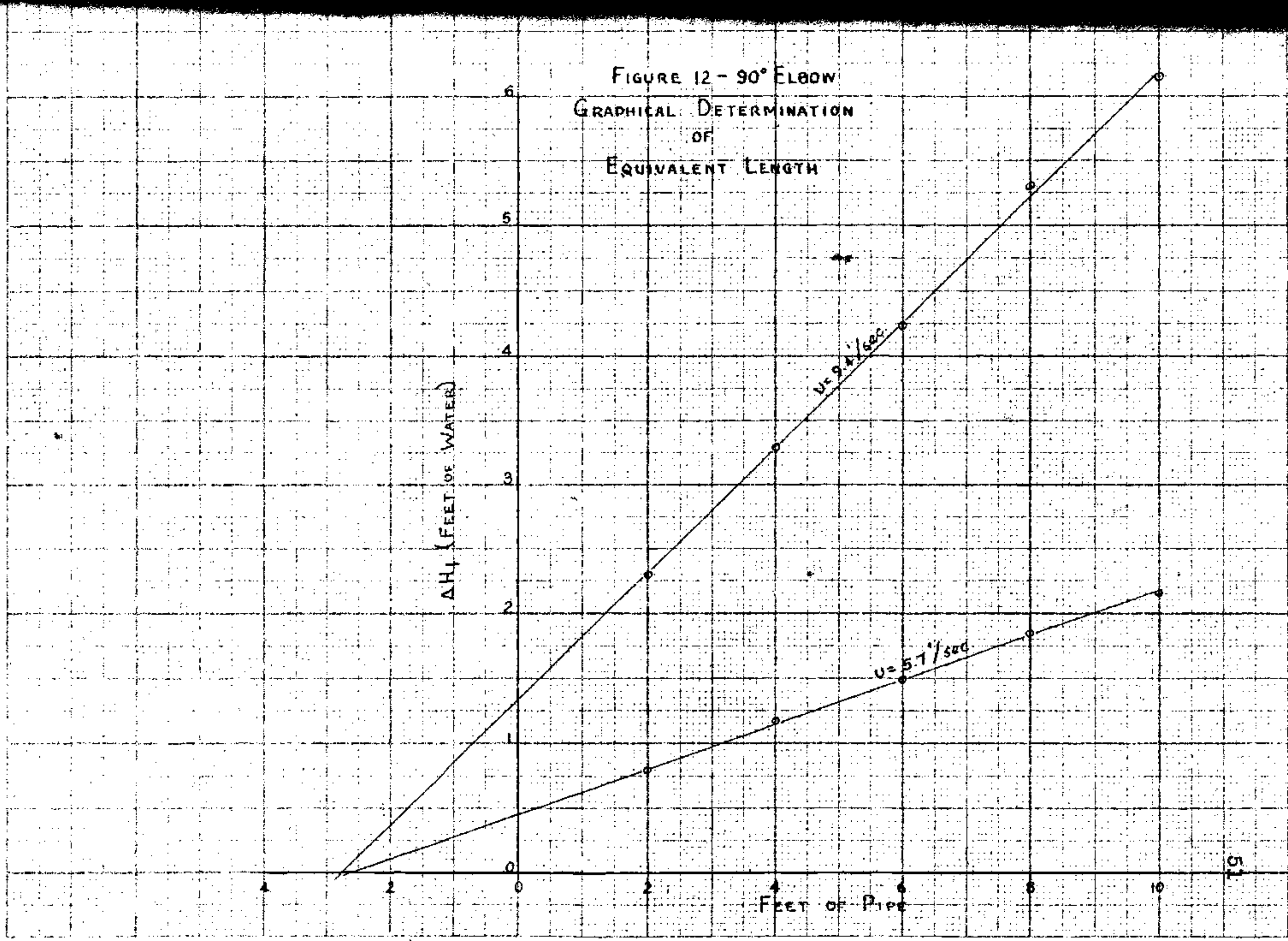

Figure 12 - 90° Elbow
Graphical Determination
of
Equivalent Length
ΔH_L (Feet of Water)
Feet of Pipe
$v = 9.4'/sec$
$v = 5.7'/sec$
0
1
2
3
4
5
6
4
2
0
2
4
6
8
10

Sample Calculations (cont.)

The equivalent length values were calculated from ΔH_f using the values obtained from Figure 6 on straight pipe.

$$\text{Reynolds Number} = \frac{D\ u\ p}{\mu} = Re$$

$D = 1.04$ in.
$u = 5.75$ ft./sec.
$p = 62.4$ lb./cu.ft.
$\mu = 1.29$ centipoises

$$Re = \frac{1.04 \times 5.75 \times 62.4}{12 \times 1.29 \times 0.000672}$$

Run I $\quad Re = 34{,}500$

$$\frac{\Delta H_f D}{u^2 L} = 0.000500 \qquad \text{Figure 6}$$

$$L = \frac{0.45 \times 1.04}{33.0 \times 12 \times 0.000500}$$

Calculation Method

L = 2.37 feet of one-inch galvanized pipe.

Graphical Method

L = 2.55 feet of one-inch galvanized pipe.

		Graph	Calculated
Run II	Equivalent Length	2.75	2.71